Fisheries and Oceans Canada | Pêches et Océans Canada
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Pacific Region

Canadian Science Advisory Secretariat
Science Response 2016/050

TECHNICAL REVIEW OF ROBERTS BANK TERMINAL 2 ENVIRONMENTAL ASSESSMENT: SECTION 10.3 – ASSESSING ECOSYSTEM PRODUCTIVITY

1.0 Context

Vancouver Fraser Port Authority (VFPA), formerly Port Metro Vancouver (the Proponent) is proposing to construct and operate the Roberts Bank Terminal 2 Project (the Project), a new three-berth marine container terminal at Roberts Bank in Delta, British Columbia. The proposed terminal is located next to the existing Deltaport and Westshore Terminals. In addition to the construction of the new terminal, the Proponent has proposed to widen the north side of the existing Roberts Bank causeway from its east-end connection with the mainland to the entrance to the new terminal. The existing tug basin, connected to the northeast side of Deltaport Terminal, is also proposed to be expanded. The new marine terminal is predicted by the Proponent to process up to 260 container ship calls per year at full capacity, with the assistance of two or three large berthing or escort tugs to manoeuver ships into or away from assigned berths. The terminal is designed to operate 24 hours per day year-round.

The Roberts Bank Terminal 2 Project is subject to an environmental assessment by a Review Panel pursuant to the Canadian Environmental Assessment Act, 2012. As a federal authority in the environmental assessment for the Project, Fisheries and Oceans Canada (DFO) will be asked to present information to the review panel and at public hearings in relation to its expertise on the effects of the Project on fish and fish habitat, including aquatic species at risk, and the adequacy of mitigation and offsetting measures and monitoring and follow-up programs proposed by the Proponent. DFO's Pacific Region Fisheries Protection Program (FPP) will coordinate DFO's participation in the environmental assessment.

The Proponent assessed future ecosystem productivity at Roberts Bank using the Ecopath with Ecosim and Ecospace (EwE) model framework. The potential impacts of the Project to hydrodynamic conditions and sediment transport in the area as a result of changes in wind, wave and current patterns and intensities, are projected using different model frameworks. A companion Science Response (DFO 2016) has been developed by DFO and Natural Resource Canada (NRCan) to review Section 9.5 "Coastal Geomorphology" of the Environmental Impact Statement (EIS) which describes the hydrodynamic and sedimentology models that were used to evaluate the effect of the Project on water and sediment movements.

Outcomes of the EwE models are incorporated into the analysis of the potential project-related effects on the ongoing productivity of commercial, recreational, and Aboriginal fisheries. Consequently, DFO FPP has requested that DFO Science Branch provide an evaluation of the Proponent's characterization of project-related effects as conducted using the Ecopath with Ecosim and Ecospace (EwE) ecosystem model.

The objectives for this Science Response are to:

1. Determine if the functional groups and abiotic factors used in the model adequately represent the ecosystem at Roberts Bank.
2. Assess whether the parameter estimates used by the model are valid and defensible for this system.
3. Assess whether the limitations and uncertainties of the model are identified and appropriately considered when determining the model's representation of current and possible future conditions.
4. Provide advice regarding whether the model results related to the potential effects of the Project on fish and fish habitat, and migratory birds and their food resources, are valid and defensible.
5. If possible, provide advice regarding the validity of using the EwE model framework to quantify large scale impacts to fish habitat and fisheries productivity, and the productivity of migratory birds.

This Science Response evaluates Section 10.0 "Biophysical Setting" with a focus on Section 10.3 "Overview of Assessing Ecosystem Productivity" in the EIS as submitted by the Proponent (Port Metro Vancouver 2015). This Section, and consequently this Response, describes the ecosystem modelling approach that was taken to evaluate the direct and indirect effects of the footprint of the proposed terminal and widened causeway, herein referred to as 'the Project'. This ecosystem model provides outputs related to potential effects of the project on the study area at an ecosystem level, including aquatic species and bird species in the Project area. Evaluation of the model and its outputs therefore required expertise in both fishery aquatic species and migratory bird species. Consequently, this Science Response is the product of a joint review between DFO and Environment and Climate Change Canada (ECCC) Canadian Wildlife Service and Wildlife and Landscape Science to provide a complete evaluation.

This Science Response Report results from the Science Response Process of July 2016 on the Technical Review of Ecopath with Ecosim and Ecospace (EwE) Ecosystem Productivity Model application to the Roberts Bank Terminal 2 Environmental Assessment.

2.0 Background

2.1 Background and Terms of Reference

The Project's main components have a proposed combined marine footprint area of approximately 1.79 km^2, listed below by specific component:

- Marine Terminal: 1.335 km^2, including terminal (1.16 km^2) and dredged berth pocket and marine approach areas (0.174 km^2)
- Widened Causeway: 0.424 km^2
- Expanded Tug basin: 0.031 km^2

Roberts Bank, in the Fraser River estuary, consists of complex intertidal and subtidal habitats, including intertidal eelgrass beds, and is an important stopover area for migrating shorebirds, and productive feeding and rearing habitats for many fish and invertebrate species. It also provides habitat for endangered Southern Resident Killer Whales and other marine mammals.

The environmental conditions at Roberts Bank are dynamic, and are influenced by a variety of oceanographic and atmospheric factors including the Fraser River freshwater and sediment plume discharge, diurnal tidal currents, and prevailing and storm-generated wind and wave activity. In addition, the intercauseway region provides significant drainage from marsh and agricultural areas, which have different characteristics from marine waters and which run along the ferry causeway.

To provide the required science advice, this Science Response focusses on Section 10 "Biophysical Setting" of the Environmental Impact Statement (EIS) (Port Metro Vancouver 2015a), specifically Section 10.3 "Overview of Assessing Ecosystem Productivity" (Port Metro Vancouver 2015b) and its related Appendices 10-B "Roberts Bank Ecopath with Ecosim and Ecospace model parameter estimates" (Hemmera 2014), Appendix 10-C "Roberts Bank Ecosystem model development and key runs"(ESSA Technologies 2014a), and Appendix 10-D "Roberts Bank Ecosystem model sensitivity analyses" (ESSA Technologies 2014b). Additional important information was obtained from the Response to Information Request #6 (IR-7.31.15-06; Canadian Environmental Assessment Agency Reference Number 80054, dated 26 October 2015) (Port Metro Vancouver 2015c) and the Written Responses to Coastal Geomorphology and Ecosystem Modelling Questions, provided by the Proponent to DFO, ECCC, and NRCan on 2 March 2016 (Port Metro Vancouver (PMV) Transmittal #TRE-01-RBT2-0004A, subsequently referred in this Science Response as "PMV Response 2016-03-02") (Vancouver Fraser Port Authority 2016).

The process followed in preparing this Science Response involved an initial review of the submitted EIS followed by an in-person meeting of the Proponent, its contractors, and representatives of DFO, ECCC, and NRCan to discuss and clarify questions arising from the initial review (Vancouver, 23 November 2015). DFO and NRCan provided written questions to the Proponent based on preliminary review of the EIS on November 19, 2015. ECCC also provided written questions based on its preliminary review of the EIS to the Proponent on December 1, 2015 and January 20, 2016. This large initial meeting was followed by smaller focussed meetings between the Proponent, its contractors, and DFO and NRCan: on 11 December 2015 to clarify hydrology and sediment modelling questions; with DFO on 8 January 2016 to clarify ecosystem modelling questions; and with ECCC on 18 February, 2016 to clarify questions relating to birds. Written responses to all of these meetings and questions were provided by the Proponent to DFO, ECCC, and NRCan as the "PMV Response 2016-03-02" and "PMV Response 2016-05-30" (Vancouver Fraser Port Authority, 2016). VFPA's answers to questions posed by DFO and NRCan regarding coastal geomorphology modelling have been posted to the Canadian Environmental Assessment Registry (CEAR).

2.2 Approach to assessing ecosystem productivity

The Proponent adopted an ecosystem approach to evaluate the direct and indirect effects of the Project on the productivity of the Roberts Bank ecosystem. A weight of evidence approach was used to assess the potential effects of the project on the productivity of the ecosystem and selected key components in the study area; this approach included a spatial ecosystem simulation model (which included a habitat capacity model), a shorebird opportunity model, and empirical data. An important point is that any effects on the system during the construction phase or from expansion of the tug basin were excluded from this modelling process, the focus instead being a comparison of modelled system productivity before and after the proposed terminal and expanded causeway is in place. The chosen ecosystem simulation model was

Ecopath with Ecosim and its spatial version Ecospace (collectively referred to here as the EwE framework, or EwE model). This modelling approach was recommended by a prior Productive Capacity Technical Advisory Group, comprised of representatives of technical experts from government agencies, academia, non-governmental organizations, Vancouver Fraser Port Authority and its consultants (Compass 2013), convened by the Proponent, and which also recommended a selection of focal species for the model. The final selection of functional groups, and the resulting food web, that form the core of this ecosystem model are shown in Figure 1.

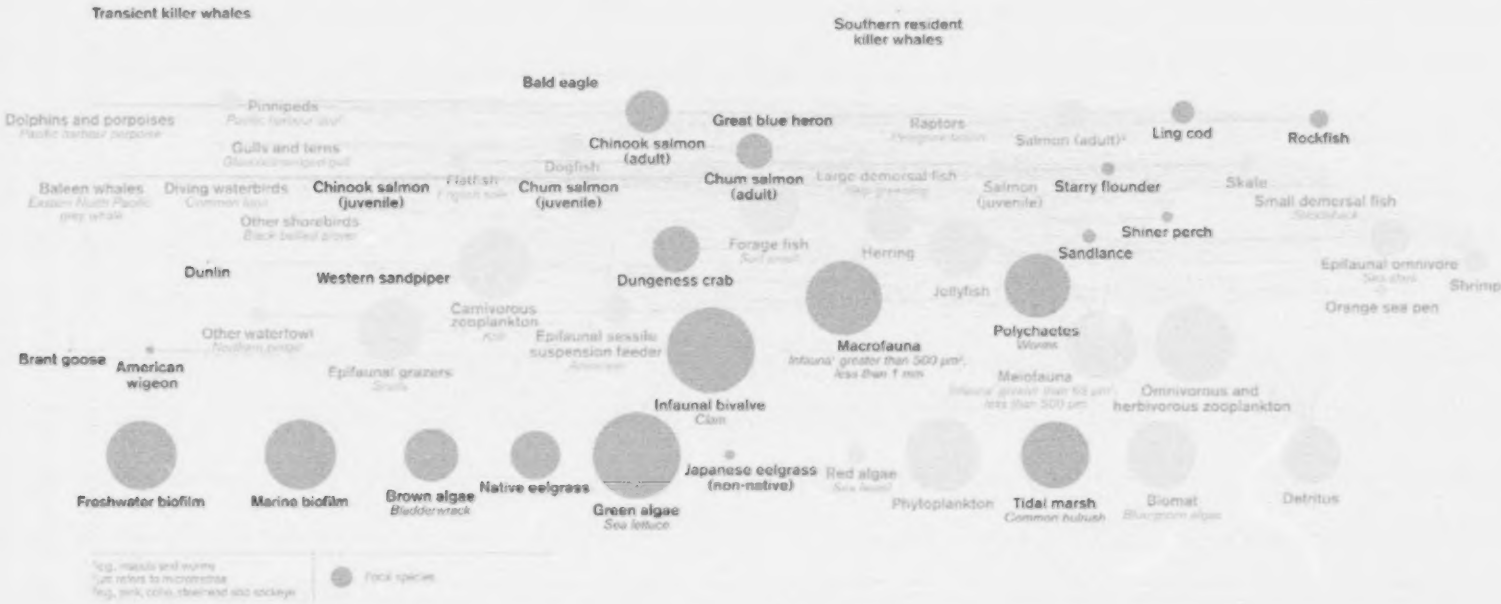

Figure 1. Ecopath with Ecosim model food web for Roberts Bank (Adapted from EIS Volume 3 Section 10, Fig. 10.3.3 on page 10-16). The groups coloured in orange represent focal groups; size of symbols represents relative annual amount of biomass in the Roberts Bank study area.

The EwE framework is a common approach to ecosystem modelling, which has been developed and expanded over the past two to three decades. It currently has three main components:

1. Ecopath – the core model which provides a mass-balance snapshot of the system
2. Ecosim – a module that enables simulation modelling over time
3. Ecospace – a module that enables simulation modelling over space

In order to make an EwE model tractable, species are aggregated into functional groups based on their similar ecological characteristics (habitat and prey preferences, etc); the Roberts Bank models had 58 functional groups. The first step (Ecopath) was to obtain input parameters representing biomass, production, consumption, emigration and diet for each functional group. These parameters were then tuned in an iterative process until the overall production and consumption was balanced (a mass-balance approach), resulting in a model food web with estimates of energy flow between functional groups (Fig. 1).

In the second step Ecosim was combined with the spatial model Ecospace. The abiotic variables selected in this EIS (depth, salinity, bottom current, wave height, sediment type) were used as external forcings to the Ecospace module. These abiotic variables provided the physical forcings for the simulations without, and with, the Project. Since time series data on the functional groups of the model were not available, Ecospace was run until the model reached equilibrium, using various assumptions of the value of the vulnerability parameter (see Section 3.5.2). In this EIS, the selected time step was annual, with all variables, abiotic and biotic, expressed as yearly averages. As used in this EIS, the Ecospace module included a habitat capacity model, which estimated the distribution of functional groups based on their environmental preferences for each abiotic variable (depth, salinity, bottom current, wave height) and for substrate type (sand, mud, etc.). The model thus allocated the spatial distribution of functional groups over the model domain based on their environmental preferences and the distributions of these abiotic variables, with and without the Project. The selected spatial unit size ("pixel") for the Ecospace model was 100 m^2. In essence, an Ecopath model was constructed for each pixel, with particular rules governing how the functional groups interacted and moved among these spatial units. The Ecospace module was run until it approached equilibrium (20 model years) to establish the spatial patterns without the Project. For the 'with the Project' simulations, the model was run for an initial 10 years, and then the spatial patterns of the abiotic variables with the project were added and the model run for an additional 10 years[1]. The model outputs predicted changes in the productive potential of the Roberts Bank ecosystem, as a comparison (ratio) with and without the Project, rather than an absolute biomass that would be lost or gained as a result of the Project.

[1] EIS, Appendix 10-C, p. 26

3.0 Analysis and Response

To prepare this response, the following sections of the EIS / additional documents were reviewed:

Document/Section	Title
EIS Section 10 Including appendices 10B, 10C and 10D (Port Metro Vancouver, 2015a, Hemmera 2014, ESSA Technologies 2014a, ESSA Technologies. 2014b)	Biophysical Setting Appendix 10-B. Roberts Bank Ecosystem Model Parameter Estimates. Port Metro Vancouver, File 302-035.03. Appendix 10-C. Roberts Bank Ecosystem Model Development and Key Run. Port Metro Vancouver. Appendix 10-D. Roberts Bank Ecosystem Model Sensitivity Analyses. Port Metro Vancouver.
CEAR document #547 (Including Appendices): "PMV Response 2016-03-02" and "PMV Response 2016-05-30" (Vancouver Fraser Port Authority, 2016)	Vancouver Fraser Port Authority to the Review Panel re: Answers to preliminary technical questions submitted during the completeness phase from Fisheries and Oceans Canada, Natural Resources Canada, and Environment and Climate Change Canada, concerning the ecosystem modelling to support the Roberts Bank Terminal 2 Project environmental review

3.1 The EwE Team

Building this ecosystem model was a complex undertaking, which required knowledge of the ecosystem to be modelled, how to set initial parameter values, determination of reasonable ranges of these parameters, how to balance the model, and how to recognize when the model outputs were unrealistic. These tasks became even more complex when spatial model dynamics were involved, such as with Ecospace. The team engaged by the Proponent to conduct this ecosystem modelling for the Roberts Bank Terminal 2 (RBT2) EIS was led by scientists at the Institute for Oceans and Fisheries located at the University of British Columbia, in Vancouver. These scientists are global leaders of the EwE model framework, having developed much of its current implementation and who continue to lead its elaborations and extensions. Construction and running of the model for this specific ecosystem was done in collaboration with ESSA Technologies of Vancouver. Parameter values for the ecosystem model were obtained in part from observational studies conducted in the area by Hemmera, of Burnaby, BC.

3.2 Overview of assessment results of hydrological and sediment modelling

Implementation of the "with the Project" simulations of the ecosystem model was done by driving the model with the abiotic variables as they were projected to be distributed with the Project footprint. In the context of this EIS, specifying depth, salinity, bottom currents, wave height and sediment type conditions without the Project, and changes with the Project, were achieved by construction of hydrodynamical and sediment transport models. The outputs from these models, in combination with the identified environment preferences for the various biological groups, were then used as inputs to the Ecospace model to define the spatial

distributions of these functional groups. The implementation of these hydrological and sediment transport models in this EIS was reviewed by DFO and NRCan (DFO 2016). This review concluded that the implementation of these models for this EIS was adequate for average winter conditions, but lacking in validation for summer conditions in particular with strong freshwater flows from the Fraser River. Simulations of strong storm events, and their impacts on wave conditions and sediment transport, were also lacking. The effect of wave action and current speeds on sediment transport is non-linear, such that increasing winds over short periods of time can impact sediment transport processes, bottom topography, and water depths beyond that determined under average model conditions. Overall, the review concluded that a greater range of sensitivity analyses is required to have confidence in the model outputs under 'non-average' conditions. The implication of this conclusion for the present review of the EwE model is that the full range of variability of abiotic characteristics such as bottom topography, bottom current, and wave heights, and how they may affect relevant functional groups in the model with the Project, may not be adequately represented. Sensitivity analyses were provided by varying the intensity of abiotic variables, and by removing abiotic variables to assess their interactive effects. In general, the ecosystem model outputs were robust to these sensitivity analyses, with most groups varying by less than 5%. Larger changes, however, were observed for primary producer and bird groupings, and for some fish groups when various abiotic variables were omitted[2].

3.3 Model implementation

3.3.1 The purpose of the EwE model

The EwE model was intended to provide one line of evidence to assess the potential impacts of the Project on the Roberts Bank ecosystem, which would then be used with other lines of evidence to make the final assessment. Specifically, "... the objective of the RB [Roberts Bank] model was not to provide an assessment of Project impacts for each functional group at a fine temporal scale, but to estimate changes in productive potential, with and without the Project, at the ecosystem level"[3]. In addition, "...the primary objective of the RB ecosystem model is to evaluate potential changes in productivity from such abiotic factors, with and without the terminal and causeway"[4]. Results are presented for the selected functional groups; no results were presented on potential changes in ecosystem structure or function.

3.3.2 Applicability of the EwE model framework to the Roberts Bank region

EwE models work best when the exchanges within the system being modelled are greater than the exchanges between the modelled system and the 'outside' world. In practice this means that EwE models work best for larger systems with few external exchanges. In a meta-analysis of 433 Ecopath models, Colléter et al. (2015) concluded that "...in the last two decades, the range of the models area has expanded toward very large areas, and the median has shifted accordingly, from about 1000 km^2 in 1984–1993 to about 100,000 km^2 in 1994–2014". The section of the Roberts Bank ecosystem that is included in the EwE model was comparatively small (54.68 km^2), and complex. It is an intertidally-dominated environment that is subject to strong seasonal influences of both freshwater and marine exchanges across relatively large seaward and shoreward boundaries.

[2] EIS, Appendix 10-D, p. ii - iii
[3] PMV Response 2016-03-02, p. 99, lines 1914-1917
[4] PMV Response 2016-03-02, p. 38, lines 689-691

Processes taking place outside the modelled ecosystem will contribute to dynamics within the modelled ecosystem (e.g. 'outside' food supporting predators which occur in the Roberts Bank ecosystem for only part of the year; predators which may feed in the Roberts Bank ecosystem but export this energy when they migrate out of the region), but which may not be well-resolved by the EwE model. The Proponent justifies the spatial scale because it was specifically chosen for the questions being asked in regard to assessing productivity changes, and because the relative influences of external exchanges are assumed to be identical with and without the project. In addition, highly mobile species with broad prey bases were assumed, in the model, to be partially sustained by external energy from outside the model system[5]. The distributions of organisms may differ, however, with and without the project, which may affect their interactions with areas outside of the modelled system, and the use of diets from outside the modelled system may not reflect the impacts of the project. Further clarification of how the EwE model captures the exchanges and interactions with adjacent ecosystems are needed. For example, it could be argued that an ecosystem which is open to frequent exchanges of water and organic matter from beyond its boundaries might be more robust to local disturbances such as the Project.

There are some inconsistencies in the information and assumptions used for some of the taxa in this ecosystem model. For Dungeness Crab, the justification for estimating total adult biomass (including females) from the biomass of fished males is unclear. In addition, it is unclear if the slower growth of female crabs once they have reached sexual maturity in comparison with male crabs has been considered. The diet matrix for spiny dogfish does not represent the actual diet well, in particular of euphausiids, herring and shrimp, and there are more recent references for biomass estimates of spiny dogfish in the study area than what was used in the EIS.

Fishing mortality was not included in the model, under the assumption that this would not change with or without the project. While this assumption may be true, the model has been parameterized by ignoring a source of mortality that will influence total production. In essence, fishing removes biomass from the ecosystem, with the result that less biomass will be available for higher trophic levels. How this may impact the ecosystem with and without the Project is unclear, but it could make noticeable differences if, for example, there were thresholds in the feeding responses by these higher trophic level species. The Ecopath model that was used is relatively unconstrained, since many ecological efficiencies are low even for forage species which would be expected to be higher. It is not clear how many species are exploited, or the levels of exploitation, but even if this does not change with the Project these mortality rates should be included in the model in order to add realistic constraints to the exploited functional groups.

3.3.3 Model documentation

Based on questions from DFO, ECCC, and NRCan following their initial review of the EIS, the Proponent provided written responses, dated 2 March 2016, to clarify several of the steps in the model development and implementation. However, several questions remain, including questions about the Ecospace module. Ecospace has undergone several recent developments, such as the inclusion of the spatial-temporal data layer framework (Steenbeek et al. 2013), the habitat capacity model (Christensen et al. 2014), and the Monte Carlo analysis including the diet matrix. As yet, there are few published studies using these latest Ecospace developments, and their documentation and justification need to be improved in the EIS.

[5] PMV Response 2016-03-02, p. 29, lines 446 - 464

Questions also remain regarding how the Monte Carlo randomization routine treated diet data. The report indicates that the Monte Carlo routine randomly selected input parameters from the input ranges, and that only models that were balanced were used. This suggests that a high proportion of models were not balanced and therefore were not used (for example, the EIS indicates that about one out of 1000 sampled input parameters was balanced[6]). A table showing the minimum, maximum, mode, average and median values from the Monte Carlo runs for all the parameters would enable an evaluation of how much variation was actually sampled by the balanced model runs. This is recommended in the EwE user information, i.e., "Users should check the range of the input parameters that were actually used in the trials in the output .csv file (see below)."[7]

In addition, there are several issues with the documentation of the derivation of the parameters for the functional groups. Such documentation should clearly outline how the input parameter was estimated and the range of uncertainty for that parameter. For example, the input biomass of pinnipeds was defined as 0.4 t km^{-2}, derived from estimates of 0.34 for Harbour seals and two estimates for Steller sea lions (0.12 and 0.14 t km^{-2}). No explanation was provided for how the overall estimated pinniped biomass of 0.4 t km^{-2} was determined. The diet of Sand Lance was described in the EIS as consisting mostly of zooplankton[8], whereas the diet table for the model runs[9] included 20% macrofauna, 10% green algae and 10% detritus. It is unclear why these additional prey were included in the diet used for the model runs.

3.3.4 Highly mobile functional groups

This implementation of the EwE framework included transient and migratory functional groups. This is entirely appropriate and these groups cannot be excluded. The approach taken in the Ecospace module was to impose a low (and conservative) dispersal rate among model spatial units ('pixels') of 1 km yr^{-1}. This may be appropriate for low mobility benthic organisms but it likely underestimates the movements of many other functional groups. The effects of using higher, and perhaps, functional-group-specific, dispersal rates was not considered. The Proponents argued that higher dispersal rates would reduce impacts since species can move away from less desirable areas more quickly, for completeness; these runs should be done and evaluated. Mobile species will also bring energy (food) captured outside the system into the modelled ecosystem. This process was included in the model with the use of a diet import factor reflecting the consumption of prey outside the modelled region, with the assumption that groups with high import rates were unlikely to respond to local changes on Roberts Bank[10]. This assumption needs justification, perhaps at the functional group level; for example, many species of highly migratory birds and Pacific salmon use the Roberts Bank ecosystem to obtain food to continue their migrations. Although this food does not compose a large fraction of their annual consumption, it can be critical to enable them to continue their migrations.

The EwE model is not designed to capture differences in prey quality, i.e. differences in essential fatty acid or nutrient ratios. The same species of prey may have greater or lesser nutritional value to predators depending on the conditions under which they are growing and their seasonal variations. This is a particular concern with the nutritional quality of the diatom-dominated biofilm. Diatomaceous biofilm is important to the highly migratory Western Sandpiper (*Calidris maun*). Despite its predictive merits in relation to other ecosystem

[6] EIS Appendix 10D, Section 2.4, p.5
[7] EwE Help file: p. 151
[8] EIS Appendix 10B, Section 4.13.3, p. 76
[9] EIS Appendix A of Appendix 10B
[10] PMV Response 2016-03-02, p. 28, lines 429 - 436

components, the EwE model is not informative with respect to understanding the potential impacts of the Project on biofilm and the Western Sandpiper. While this example is specific to seabirds, the potential exists for differences in the quality of biofilm to also be an issue for copepods which feed on biofilm and, consequently, to juvenile salmon which feed on these copepods (e.g. Sutherland et al. 2013).

The EwE model is also not designed to predict effects of the Project on water quality, although the Proponent noted that "Other abiotic factors not included were deemed to be representative of variables that were already included in the model..."[11]. The Project may cause changes in physical and water quality conditions, whether in isolation or in combination, which may impact the productivity or nutritional quality of key prey organisms for local and migratory species which will not be captured by the model. The EwE model does not assess the production of key nutrients or the implications of changes in important physical and water quality parameters to biofilm community structure, and hence to important migratory birds.

The model does not include biotic factors for both pelagic and benthic environments to assess the potential development of eutrophication and benthic organic enrichment events, respectively. Organic and redox indicators, traditional measures of environmental assessments that are used to determine changes in functional group responses, were included in the recent Deltaport Third environmental assessment (i.e. Pelagic: chlorophyll, dissolved nutrients; Benthic: sediment carbon/nitrogen content, redox state [sulfide concentration]). Benthic anoxic events based on organic enrichment are known to be strong drivers of community composition and exclusion, regardless of substrate type. In the absence of biotic factors (e.g. organic particulates), the model has not considered the potential for benthic organic enrichment which coincides with siltation processes within the upper tidal flats. The tidal flat corner bordered by the Delta-dyke and Deltaport causeway has served as a catchment area for Fraser River silt since the development of the original Deltaport causeway (Sutherland et al. 2013). The proposed position of the new terminal placed at the seaward termination of the Deltaport causeway may produce a crescent-shaped feature in the wake of the Fraser River Plume. This feature may provide a more efficient silt trap that will promote benthic organic enrichment. This piece of the environmental assessment seems to be missing and is important for assessing fish habitat in this area.

3.3.5 Seasonality (model time step)

Input data to parameterize the model were available on a range of time scales, from hourly (e.g. physical data on salinity and water flow) to annual (e.g. species biomass). The Proponents indicated[12] that this is a strength of the EwE model, although ultimately the model was run with an annual time step, with all sub-annual values being averaged to annual values. This method therefore did not incorporate important seasonal processes such as winter-summer differences in salinity and storm properties, and the seasonal appearances of abundances of predators and prey such as migratory salmon and birds that are much larger than the annual average. For example, juvenile salmon migrate from the Fraser River and onto Roberts Bank in the spring, before moving into deeper waters. If these spring abundances are averaged over the entire year, these average abundances would be 5-10 times lower than the actual abundances during the spring (i.e. averaging the biomass that occurs in two months over a 12 month period). Additionally, this method did not capture the intensity of processes, such as growth and predation, which can be focused over periods of a few weeks to a few months. There may be important threshold effects at particular times and places which may be missed when using an

[11] EIS, Section 10, p. 10-11.
[12] PMV Response 2016-03-02, p. 86, line 1655

annual time step for the model. The Ecospace module has a monthly time step[13], and therefore it is feasible to run this module with a sub-annual time step. For example, the Proponents submit[14] that there are inadequate data to model the potential effects of the Project on the timing of biofilm production, which could have implications for the migratory dunlin and Western Sandpiper. However, this could be modelled in an exploratory way to determine hypotheses about which factors could affect the timing of production of biofilm and the potential impacts on these birds. These issues are of major concern to ECCC.

3.3.6 Life history structure

The EwE model did not separate functional groups into life history stages (stanzas), yet for many functional groups the juvenile stages can have very different life history characteristics and habitats than the adults. It is unclear in the description of the model how different life history structures were considered, and whether, for example, there were enough juveniles to produce the adults. The implications of not including early life stages should be explored, at least qualitatively, to identify which species might have life stages that may be more vulnerable to project effects.

3.3.7 Model balancing

Balancing an EwE model is the process by which parameters are adjusted so that there is sufficient production for consumption requirements, i.e., there are sufficient prey for all predators. Expert opinion was used to examine parameter values and to adjust for errors or inconsistencies in logic. "PMV is confident that since the approach taken to balance the model was based on best practices, the steps are appropriate"[15]. Adjustments to initial parameters to ensure an ecologically-feasible model are necessary and to be expected. For a few functional groups, however, very large changes to initial parameter estimates (which were often not based on Roberts Bank specific data) were necessary, for example to transient killer whales. When such initial parameters were adjusted (often by substantial amounts) by expert opinion to balance the model, the confidence intervals around these adjusted parameter values were not increased to reflect this added uncertainty (see for example PMV Response 2016-03-02, p. 51, lines 955-956). When expert opinion was used to make very large changes to initial parameter values, broader confidence intervals about these parameters should have been applied. This does not appear to have been the case and, as a consequence, may cause the actual uncertainty of the model outputs to be underestimated.

Another example is for the pinniped group, in which 50% of the diet was assumed to come from outside the model area in order to balance the model. The rationale provided was: "The pinnipeds caused excessive predation mortalities on numerous fish functional groups. The biomass of pinnipeds was an average for the Strait of Georgia, which was likely too high for Roberts Bank. Therefore, it was assumed that pinnipeds extracted only half of their diet from the study area"[16]. It is unclear whether the sensitivity of the model to different percentages of diet allocation was explored.

As noted above (3.3.2), the Ecopath model was relatively unconstrained, and few adjustments to input parameters were required to balance the model. This is unusual and the low ecotrophic efficiencies of several functional groups suggest that full accounting of energy flows may not have been achieved (an ecotrophic efficiency of 1 indicates that 100% of the production of that

[13] EIS Appendix 10C, Section 2.9, p.24
[14] EIS Appendix 10D, Appendix C, p.72
[15] PMV Response 2016-03-02, p. 49, lines 910-912
[16] EIS Appendix 10C, Section 2.6.1, p. 20

particular group is being preyed upon or removed by fishing, leaving no individuals to die of old age[17]). An "excess" of individuals dying of old age, i.e. ecotrophic efficiencies much less than 1, suggests a potentially large biomass that is not used by the ecosystem, and instead is converted to detritus.

3.4 Model validation

Model validation is the process by which the model parameters, variables, and outputs are compared with those from the real ecosystem to ascertain how well the model represents the ecosystem. It is an essential step in providing confidence that the projections from the model, in this case with and without the Project, have relevance to how the real ecosystem may be expected to function with and without the Project. In practice, validating complex ecosystem models is difficult, considering the range of assumptions that must be made when building the model, the limited available data, and natural variability of the ecosystem at a variety of time and space scales.

Many of the standard diagnostics for the Ecopath model have not been evaluated in the EIS. The Proponent appears to have assumed that once the Ecopath model was balanced, then it was valid and fit for purpose. The Proponent should provide all the Ecopath estimates of vital rates, including mortality rates. As presented, questions remain. For example, many Ecotrophic Efficiencies (which control the transfer of biomass from prey to predators) are less than 1, even for taxa which would be expected to be close to 1 such as carnivorous zooplankton. The reason for Ecotrophic Efficiencies less than 1 were not discussed or explained in the EIS.

Detailed diagnostics for the Ecospace model should also be presented in order to evaluate model performance. In response to criticisms by DFO, ECCC, and NRCan in discussions with the Proponent, the latter provided the biomass of the functional groups from the Ecopath model (before Ecospace) and the Ecospace model, after the spin-up period (which involved adjusting the parameters from the Ecopath model to balance the 5468 separate cells of the Ecospace model)[18]. The Proponents argue that "It is important to note that changes in biomass values generated during the spin-up period are identical for both with and without Project scenarios and thus do not provide information on the potential Project-related effects on productivity[19]. However, several changes to biomass result from the Ecospace balancing process (spin-up period). This is only given brief attention by the Proponent in its response to the DFO, ECCC, and NRCan questions. An analysis of Table 6[20] revealed that the biomass of 9 functional groups was larger or smaller than the widest confidence limits allowed for each group[21]. This requires further discussion and justification.

The Proponent used a goodness of fit measure to compare spatial distributions of model outputs with field observations. They indicated that "no other EwE models were identified which use a goodness-of-fit measure. Hence, the RB model is potentially the first such EwE model where a goodness of fit measure has been applied"[22]. The chosen goodness of fit measure is the percent correct classification (PCC) method[23]. This method derives a test statistic based on the proportion of locations at which predicted occurrences from the model match observed

[17] EIS Appendix 10-B, p. 11
[18] PMV Response 2016-03-02, p. 65-66, Table 6
[19] PMV Response 2016-03-02, p. 64, lines 1205-1207
[20] PMV Response 2016-03-02, p. 65-66, Table 6
[21] PMV Response 2016-03-02, p. 45, Table 3
[22] PMV Response 2016-03-02, p. 78, lines 1481-1483
[23] PMV Response 2016-03-02, p. 78, lines 1483-1484

occurrences from data, and similarly with predicted and observed absences. The Proponent then calculated two additional accuracy of fit measures: sensitivity (the model predicts a species to occur in an area where it is known to occur in reality), and specificity (the model predicts a species does not occur in an area it is known not to occur in reality)[24]. This analysis concluded that the model has high predictability for functional groups such as eelgrass and sea pens with relatively static distributions, but lower predictability for functional groups which are more temporally and spatially dynamic, such as biofilm and green algae[25].

There are two problems with this approach. The first is that this goodness of fit comparison was done only for habitat-forming functional groups; no discussion of how well this analysis applies to mobile functional groups was provided. The second problem is that this method does not take into account situations (such as occurs in this study with several groups) in which species occur at only a few locations. For example, "...if the test data consist of 95% absences and 5% presences, and this reflects the true prevalence of the species on the landscape (a realistic scenario for a rare species), a 'null' model that predicted absence in all cases (e.g., no model at all) would be correct 95% of the time..." (Franklin 2009, p 151). This latter point is important here, as these habitat functional groups (biofilm, brown algae, native eelgrass, green algae, Japanese eelgrass, tidal marsh, biomat, and orange sea pens[26]) appear not to occur over most of the Project area (as portrayed by the model outputs presented in the distribution figures of PMV Response 2016-03-02 Appendix 2.18). It is therefore important that a robust evaluation of the performance of the Ecospace module is used, with preferably more than one measure.

In summary, the starting point for this modelling analysis matters. It is not just about a comparison between results with and without the Project. The model has to be considered a sufficient representation of the ecosystem. The Proponent has not yet sufficiently validated the model.

3.5 Model results

3.5.1 Presentation of model results

As noted above (Section 3.3.1), the stated objective of the Roberts Bank ecosystem model was not to provide an assessment of Project impacts for each functional group at a fine temporal scale, but to estimate changes in productive potential, with and without the Project, at the ecosystem level[27]. However, results were presented as comparisons by species/functional group with and without the Project, and not as potential changes in total ecosystem productivity. The revised figures for each functional group showing distributions without the Project, with the Project, and their difference indicated impacts were likely to be localized, with overall impacts relatively small. The range of biomass ratios with and without the Project was 0.45 – 1.89, with most values slightly less than 1. This is interpreted as indicating slight decreases in the capacity of the study area to support biomass and production with the Project for many functional groups[28] (Figure 2).

[24] PMV Response 2016-03-02, p. 80, lines 1524-1527
[25] PMV Response 2016-03-02, p. 81, lines 1551-1559
[26] PMV Response 2016-03-02, p. 82, Table 8
[27] PMV Response 2016-03-02, p. 99, lines 1914-1917
[28] PMV Response 2016-03-02, Appendix 2.18

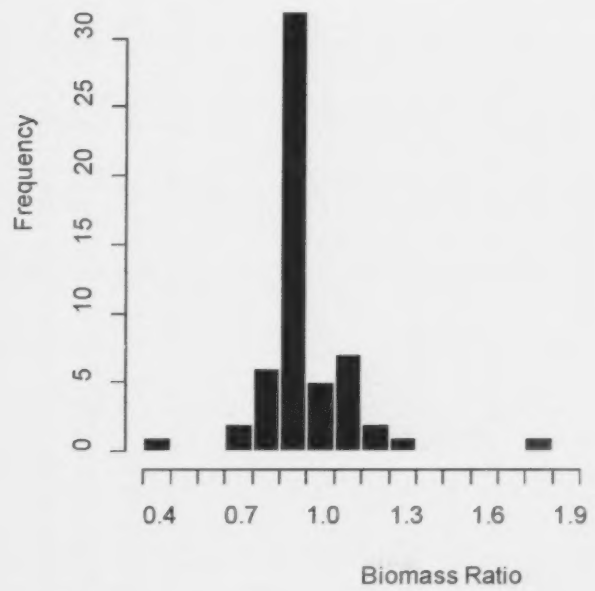

Figure 2. Histogram of biomass ratios obtained by comparisons of model runs with and without the project (i.e. With / Without). Values less than 1 indicate reductions in biomass with the Project compared against without the Project). Data from Appendix 2.18 of PMV Response 2016-03-02.

3.5.2 Sensitivity and vulnerability analyses

Every ecosystem model is only one possible representation of the true ecosystem, defined by the model's structure and the values chosen for its many parameters. The key point is how well the model represents the real system, how that fit can be measured, and the sensitivity of model outputs to variability in the selected parameter values. The ideal model should be robust to a wide range of uncertainties in the input data and parameters. This robustness is determined by performing sensitivity analyses on the model to see how it responds to variations in the input parameters, and determining to which input parameters the model is most sensitive.

The vulnerability parameters determine the strength of the feeding interactions between functional groups. They set the level of density dependence of each functional group. Higher vulnerability settings provide greater top-down (predator) control, whereas lower settings provide greater bottom-up (environmental) control[29]. Several publications have shown that EwE models are very sensitive to the vulnerability parameters, and Christensen and Walters (2000) point out that a main pitfall of EwE is that "predation vulnerabilities are often underestimated, lessening the modelled impacts of predation". It is usual practice to tune Ecopath models, including the vulnerability parameters, to time series data, such as biomass, using the temporal simulation model, Ecosim. However, these data were not available for the RBT2 area, so this robust method of fitting the model and estimating vulnerability parameters was not possible. Instead, a vulnerability setting of 2 was used as the default value for the key model runs, which is "common practice when time series data are not available and estimates of vulnerability in the

[29] PMV Response 2016-03-02, p. 70, lines 1318-1323

model cannot be made"[30], with sensitivity analyses run for a range of 1.5 to 3. This narrow range was criticized by DFO/ECCC in initial discussions about the model with the Proponent. The Proponent subsequently reran the model with a larger range of vulnerabilities[31] (1.1 to 10), and concluded this broader vulnerability range produced similar results for the productivity ratio with and without the Project to those in the original EIS, and that the EIS was more likely to overestimate than underestimate potential project effects[32]. The data in Table 7 of the PMV Response[33] did indicate changes in productivity ratios ranging from 0 to 50% of the defined key run (which used a vulnerability setting of 2). However, the Proponent changed all vulnerability settings to the same value, i.e., all were 2, or all were 10, etc. In reality, the vulnerability parameters resulting from Ecosim models that are fitted to data, as described above, vary by functional group, which was not explored here. Therefore, although the results suggest that the original choice of 2 for the default key run seemed reasonable, the potential effects of variability in vulnerability settings was not fully explored.

Sensitivity analyses are usually based on the range of uncertainty estimated for input data and parameters, often called the confidence limits around the model parameters. The EwE framework integrates many different data sources and parameters, including values from the literature. It can therefore be difficult to identify "reasonable" confidence limits when derived from such diverse data sources. Standard practice in Ecopath models has been to develop a pedigree for each parameter, with default values for uncertainty based on the nature of the source data. For example, parameter values based on high precision field observations of biomass within the model domain receive default confidence intervals of 10%, whereas parameter values based on models developed for elsewhere or professional judgment receive confidence intervals of 80%[34]. Sensitivity analyses are then run using parameter values selected from within these confidence intervals. However, if these default confidence intervals do not capture the full range of variability, then the outputs are not informative of the variability in the 'real' ecosystem. Field observations were collected for many functional groups within the model domain in 2012 and 2013, as part of studies to support the RBT2 EIS. Apparently, the purpose of these observations was to document spatial variability (in part for the Ecospace model) and temporal variability (measurements at one location over time), and not to derive confidence intervals around the observations[35].

The reliance on the pedigree approach to derive confidence intervals for this Roberts Bank model was criticized by DFO, ECCC, and NRCan in discussions with the Proponent. As a result, the Proponent reran the model with much larger confidence intervals, ranging from 30 to 100% depending on the input parameter and functional group[36]. The results from this new analysis using the broader confidence intervals were similar to those using the original pedigree approach. The Proponent noted that "While the production within each ...run was very different, there was little difference in the biomass ratio [with and without the Project]. These results further demonstrate that even with a greater range in input values, the influence of the Project on the Roberts Bank ecosystem is consistent among all...model runs"[37]. This provides confidence that the model may be robust to uncertainty in its input parameters. Two concerns

[30] PMV Response 2016-03-02, p. 70, lines 1321-1322
[31] PMV Response 2016-03-02, p. 71-74
[32] PMV Response 2016-03-02, p. 71, lines 1339-1341
[33] PMV Response 2016-03-02, p. 73
[34] EIS, Appendix 10-C, Section 2.5.1, page 18
[35] PMV Response 2016-03-02, p. 42, lines 772-777
[36] PMV Response 2016-03-02, p. 44-47
[37] PMV Response 2016-03-02, p. 47, lines 855-858, and see also PMV Response 2016-03-02 Appendix 2.7-B

remain, however. The quote above indicates that the production among the different model runs was very different, although with little difference in the biomass ratios with and without the Project. Since biomass is not the same as production, it would be informative for understanding model performance and potential impacts to show these production differences. This also relates to the point made in Section 3.4 regarding how well the model represents the real ecosystem, and not just within-model comparisons with and without the Project. The second question is more technical, and relates to how the randomization (Monte Carlo, or MC) routine that was used to create multiple model runs used the uncertainty about the diet data. Diets are not currently included in the MC routine available to regular users of the Ecosim model; how they were handled in this RBT2 model appears not to be explained.

Finally, the sensitivity analyses indicate that the uncertainty in the input parameters does not lead to much difference between model parameters with or without the project. However, this conclusion does not describe how the uncertainty in the input parameters affects understanding of the ecosystem.

4.0 Conclusions

Overall, the main conclusion of the Environmental Impact Statement from the Proponent is stated as "...after the implementation of mitigation, ...the Project is not expected to result in any significant adverse effects on any of the 16 valued components."[38] In addition, "...approximately 40% of the functional groups are forecast to change no more than 5%, which ... is judged to be within the uncertainty of the model runs"[39], although larger changes were forecast for orange sea pens, freshwater biofilm, green algae and raptors. The conclusions from the modelling studies are that "...the proposed project will have an impact on the study area, that the effect varies between species, and that the findings are robust to parameter uncertainty."[40] Specific outcomes by valued component as derived from the EwE model are presented by functional groups in Table 1.

[38] PMV, March 2015, Roberts Bank Environmental Impact Statement Executive Summary – Part 1, page 37
[39] EIS, Appendix 10-C, p. ii
[40] EIS, Appendix 10-D, p. iv

Table 1. Changes in productive potential with the Project as derived from the EwE model.

			Changes in productive potential					
Ecosystem category	Number of valued components	Number with potential biomass loss	Moderate decrease (31-60% decline)	Minor decrease (6-30% decline)	Negligible (0-5% change)	Minor increase (6-30% increase)	Moderate increase (31-60% increase)	Source
Marine vegetation	7	7	-	3	2	2	-	EIS, Vol. 3 Section 11, Table 11-17, page 11-65
Marine invertebrates	4	3	1	1	1	1	-	EIS, Vol. 3 Section 12, Table 12-8, page 12-52
Marine fish	13	13	-	2	6	5	-	EIS, Vol. 3 Section 13, Table 13-10, page 13-95
Coastal birds	11	8	-	3	4	3	1	EIS, Vol. 3 Section 15, Table 15-10, page 15-67

Most functional groups showed some potential biomass loss with the Project, with biomass loss defined as any model run with negative outcomes (i.e. in which biomass with the project was less than biomass without the Project). The summary of changes in productivity potential are mixed, with most (33 out of 35) valued components showing minor decreases to minor increases (defined as 6 to 30% changes in productive potential with the Project compared to without the Project).

The main conclusions of this review in regards to the Terms of Reference are:

1. Do the functional groups and abiotic variables used in the model adequately represent the ecosystem at Roberts Bank?
    - The 58 functional groups and abiotic variables used in the model adequately represent the main components of the Roberts Bank ecosystem; however, for longer lived species, the life stages of the species are not well represented, and some of the impacts of the Project may be expected to affect specific life stages.
    - The abiotic variables adequately represent the physical drivers of this ecosystem on an annual time scale. However, annual values for these abiotic variables may not adequately capture important sub-annual events such as storms (DFO. 2016), the timing of arrival and departure of highly migratory species, and whether there may be important sub-annual thresholds or mismatches in timing as a result of the Project.
    - Biotic factors (e.g. nutrients), which are particularly important for biofilm and other lower trophic level taxa, are not included in this model. The model is therefore unable to assess the potential development of eutrophication and benthic organic enrichment events, which may affect fish habitats in the study area.
2. Are the parameter estimates used by the model valid and defensible for this system?
    - In general, parameter estimates appear to be adequate for this system. Field studies were done in two years to provide data, in particular, on distributions of selected functional groups for the Ecospace module. Note the distribution studies focussed on taxa which were relatively immobile and therefore 'fixed' in space;
    - the selection of some model parameters would benefit from further explanation, for example the choice of fixed diet matrices versus dynamic matrices which can vary with changes in abundances or predators and prey;
    - the selection of some model parameters would benefit from further explanation, for example the link between the diets described in the text of Appendix 10B and the quantities presented in Appendix A of Appendix 10B. It is understood that proportions were derived using the "fixed selectivity" principle, but in order to be fully transparent, the derivation of each diet should be provided in an appendix;
    - discussion and explanation is needed of why ecotrophic efficiencies differ from expected values (e.g., the ecotrophic efficiency for Pacific herring is listed as 0.38); and
    - the abiotic factor, 'substrate', was limited to "hard" or "soft" options, which can be restrictive given that they serve as endpoints on a substrate composition continuum. These limited options may not provide the sensitivity required to assess substrate preference nor the flexibility for taxa (e.g. motile organisms) that span hard, mixed, and soft substrate types. In addition, it is not clear if changes in the hard/soft categories were considered over time within identified depositional or erosional settings before and after construction.

3. Are the limitations and uncertainties of the model identified and appropriately considered when determining the model's representation of current and possible future conditions?
    - the EwE model was not designed to evaluate a range of future conditions. It was designed to estimate changes in the productive potential at the ecosystem level, with and without the Project. Therefore, the model was run without the Project, and with the Project, for a range of plausible abiotic conditions, and the results were compared with respect to biomass and productivity by functional group;
    - the pedigree approach to assessing the uncertainties of model outcomes is unsatisfactory for the purpose here, as it relates solely to a qualitative judgment of the value of data based on its source. However, when the model was rerun with much wider ranges of confidence intervals (uncertainties) the results in general (but not necessarily for each functional group) were similar to the results using the original pedigree approach. This suggests that, taken overall, the model may be robust to wide ranges of uncertainty in these input variables and parameters;
    - there is inadequate validation of the model. This is inadequate for three reasons:
        (i) the basic Ecopath model is not validated, and the Ecospace balancing process (the spin-up period) resulted in some biomass estimates being increased or decreased beyond their confidence limits;
        (ii) the goodness of fit test used to evaluate how well the model predicted the spatial occurrence functional groups is not fit for purpose (Section 3.4); and
        (iii) validation was provided for only a small number of functional groups (the habitat-forming functional groups). As a consequence, the model is currently not validated.
    - Considering the proportion of open boundaries relative to closed boundaries in the model, processes taking place outside the modelled ecosystem are likely to contribute to dynamics within the modelled ecosystem. However, these external processes may not be well-resolved by the EwE model as currently configured.
4. Are the model results related to the potential effects of the Project on fish and fish habitat, and migratory birds and their food resources, valid and defensible?
    - this is a very complex ecosystem model, constructed for a relatively small and open (in the sense of considerable exchange with adjacent non-modelled areas) system. Many assumptions have been made based on poor or missing data. Taking all these considerations into account, the model does the best job possible of comparing the biomass and productivity of the Roberts Bank ecosystem with and without the Project;
    - the extent to which the model adequately represents the 'real' ecosystem of Roberts Bank, as opposed to comparisons of model results with and without the Project, is unclear as a number of basic diagnostics are not presented (see point 3 above);
    - the EwE model is not capable of, and is not designed to, represent nutritional and food quality variations in prey functional groups, and how these may impact highly migratory predators such as birds, with and without the Project.
5. Is the EwE model framework a valid method to quantify large scale impacts to fish habitat, fish productivity, and migratory bird productivity?
    - the EwE model, as implemented in this project and reviewed here, is a useful first-order framework to organise information and derive initial estimates of how the system may respond to perturbations;

- the utility of a EWE model for impact purposes is highly dependent on the quality of input data;
- each EwE model is highly dependent on local conditions. Although appropriate as an overall methodology, each application would need to be reviewed for how it may be applied to any new ecosystem; and
- the EwE model would need to be substantially reformulated if it was to include considerations of changes in chemical composition or food quality of prey, in particular for seasonal migratory species such as birds which may depend on very large biomasses of prey with specific chemical composition to fuel their migrations beyond the ecosystem model boundaries.

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November 4, 2016

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This Report is Available from the

Centre for Science Advice
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ISSN 1919-3769
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Correct Citation for this Publication:

DFO. 2016. Technical review of Roberts Bank Terminal 2 environmental assessment: section 10.3 – assessing ecosystem productivity. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/050.

Aussi disponible en français :

MPO. 2016. Examen technique de l'évaluation environnementale du Terminal 2 à Roberts Bank : section 10.3 – évaluation de la productivité de l'écosystème. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2016/050.